PATENT APPLICATION

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re application of

Takuo FUNAYA, et al.

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For: SOLDER AND PACKAGE USING THE SAME

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Mail Stop Amendment
Commissioner for Patents
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Alexandria, VA 22313-1450

Sir:

I, Takuo Funaya, hereby declare and state:

THAT I am a citizen of Japan;

THAT I have received the degree of master in the subject of engineering from the following institution: Tohoku University;

THAT I have been employed by NEC Corporation since 1996, where I hold a position as Assistant Manager, with responsibility for research on device packaging;

THAT I am familiar with the subject matter of the present application; and

THAT the experiments reported below were conducted by me or under my supervision.

Hereinbelow are explained the improvement in tensile strength, breaking elongation, Vickers hardness, and shearing strength in the solder in accordance with the present invention.

1. Elongation

If a solder is elongatable, then the solder may relax a stress when the solder is used for a long time under circumstances in which the solder is kept stressed. Accordingly, an elongatable solder may have a long lifetime.

FIG. 1, attached hereto, is a graph showing tensile elongations of a solder in a tensile test. The solder used in the tensile test contained Ag at Y weight %, Zn at 8 weight %, Bi at 1 weight %, and the remainder of Sn, wherein "Y" is a variable.

As illustrated by FIG. 1, in comparison with a solder containing no Ag or containing Ag at 0.1 weight % or greater, the tensile elongation rate before fracture is significantly improved in the solder containing Ag at X weight % (where $0.001 \leq X < 0.1$), in particular, at Z weight % ($0.025 \leq Z < 0.1$).

The data above illustrates that tensile elongation is smaller in a solder containing Ag at 0.1 to 0.5 weight % than in the solder of the present invention.

2. Tensile strength

FIG. 2, attached hereto, is a graph showing the tensile strength of a solder in a tensile test. The solder used in the tensile test contained Ag at Y weight %, Zn at 8 weight %, Bi at 1 weight

%, and the remainder of Sn, wherein "Y" is a variable. FIG. 2 additionally shows data of a conventional solder including Pb at 37 weight % and the remainder of Sn, as reference data.

As illustrated in FIG. 2, the tensile strength of the solder containing Ag at X weight % ($0.001 \leq X < 0.1$) is equal to or better than the tensile strength of a solder containing no Ag. In particular, the tensile strength of the solder containing Ag at 0.025 weight % and at 0.075 weight % shows its maximum peak, and is higher than the tensile strength of the solder containing no Ag or containing Ag in an amount of 0.1 weight % or greater. The tensile strength in the solder containing Ag at 0.05 weight % shows a minimum peak, but even that peak shows a tensile strength that is comparable to or greater than the tensile strength in a solder containing no Ag, when measurement dispersion is taken into consideration.

FIG. 2 also illustrates that the tensile strength in the solder containing Ag at 0.05 weight % is equal to or greater than the tensile strength of the reference Sn-Pb solder containing Pb, which is hazardous to the atmosphere. Since the solder containing Ag at 0.05 weight % shows its maximum peak with respect to an above mentioned tensile elongation, it can be said that the solder has high tenacity.

In a solder containing Ag at 0.1 to 0.5 weight %, Ag exerts slight influence on the tensile strength, and the above-mentioned tensile elongation is small. Hence, the data in FIG. 3 shows that the solder in accordance with the present invention has higher tensile strength and higher tenacity (because it is elongatable), and as a result has higher reliability than a solder containing Ag in an amount of 0.1 weight % or greater.

3. Vickers hardness

FIG. 3, attached hereto, is a graph showing the Vickers hardness of a solder containing Ag at Y weight %, Zn at 8 weight %, Bi at 1 weight %, and the remainder of Sn, wherein "Y" is a variable. FIG. 8 also shows the Vickers hardness of a conventional solder including Pb at 37 weight % and the remainder of Sn, as reference data.

One of the reasons why conventional Sn-Pb solder has been long used is its softness, which is illustrated in FIG. 3.

Since a hard solder has little flexibility, a hard solder is likely to be cracked and then broken when subjected to an internal or external stress load. In contrast, a soft solder can absorb internal or external stress by deforming. A soft solder can thereby present high reliability.

As illustrated in FIG. 3, the solder containing Ag at X weight % ($0.001 \leq X < 0.1$) is softer than a solder containing no Ag or containing Ag in an amount of 0.1 weight % or greater. Thus, FIG. 3 shows that the solder of the present invention has high tenacity.

4. Vickers hardness at high temperature

FIG. 4, attached hereto, is a graph showing how Vickers hardness of an ingot kept at 85°C in an electric furnace for more than 1000 hours varies.

In the solder containing Ag at X weight % ($0.001 \leq X < 0.1$), a significant increase and reduction of the Vickers hardness of the ingot were not found. This means that the solder of the present invention keeps preferable flexibility as compared to a solder containing no Ag or containing Ag in an amount of 0.1 weight % or greater.

FIG. 5, attached hereto, includes SEM images of the samples used in FIG. 4 for measuring Vickers hardness, each sample containing Ag at Y weight %, Zn at 8 weight %, Bi at 1 weight %, and the remainder of Sn, wherein "Y" is a variable.

As is understood from FIG. 5, a Zn-rich phase (the black contrast area in FIG. 5) was kept minute (i.e., very small) in the solder containing Ag at X weight % ($0.001 \leq X < 0.1$). In contrast, in a solder containing Ag in an amount of 0.1 weight % or greater, a Zn-rich phase grew large from the start of measurement, and even after the solder has been heated for 1000 hours. It is known that if a Zn-rich phase is large, then a brittle ZnO phase is formed (due to oxidization), which results in a reduction in the solder's strength.

Thus, it is understood that a Zn phase is dispersed in the solder of the present invention containing Ag at X weight % ($0.001 \leq X < 0.1$), and hence, even if Zn is oxidized, a brittle ZnO phase is dispersed in the solder of the present invention. Furthermore, it is considered that solution of Ag would increase a strength of the solder.

Conclusion

FIG. 6, attached hereto, is a graph showing the tensile strength of a solder containing Ag at Y weight %, Zn at 8 weight %, Bi at 1 weight %, and the remainder of Sn, wherein "Y" is a variable, and further showing the Vickers hardness of the solder, observed after the solder was kept heated at 85°C for 1000 hours.

The area surrounded with a broken line "A" indicates solder in accordance with the present invention, containing Ag at X weight % ($0.001 \leq X < 0.1$), and the area surrounded with a broken line "B" indicates a solder containing Ag at Z weight % ($0.025 \leq Z < 0.1$).

The tensile elongation in the area "A" is improved relative to a solder containing no Ag or containing Ag at 0.1 weight % or greater. In particular, the tensile elongation in the area "B" is improved relative to both a solder containing Ag at S weight % ($S < 0.025$) and a solder containing Ag at T weight % ($0.1 \leq T$).

The Vickers hardness in the area "A" is smaller than a solder containing no Ag or containing Ag at 0.1 weight % or greater.

The tensile strength in the area "A" is kept higher than the same of a conventional hazardous Sn-Pb solder, and is comparable to or higher than the tensile strength of a solder containing no Ag.

Furthermore, it is possible to prevent a brittle ZnO phase from growing when the solder is kept at a high temperature by adding Ag into a solder at X weight % ($0.001 \leq X < 0.1$). Accordingly, the lead-free solder in accordance with the present invention is elongatable and has high strength and high tenacity.

I declare further that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States

Code, and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

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FIG.1

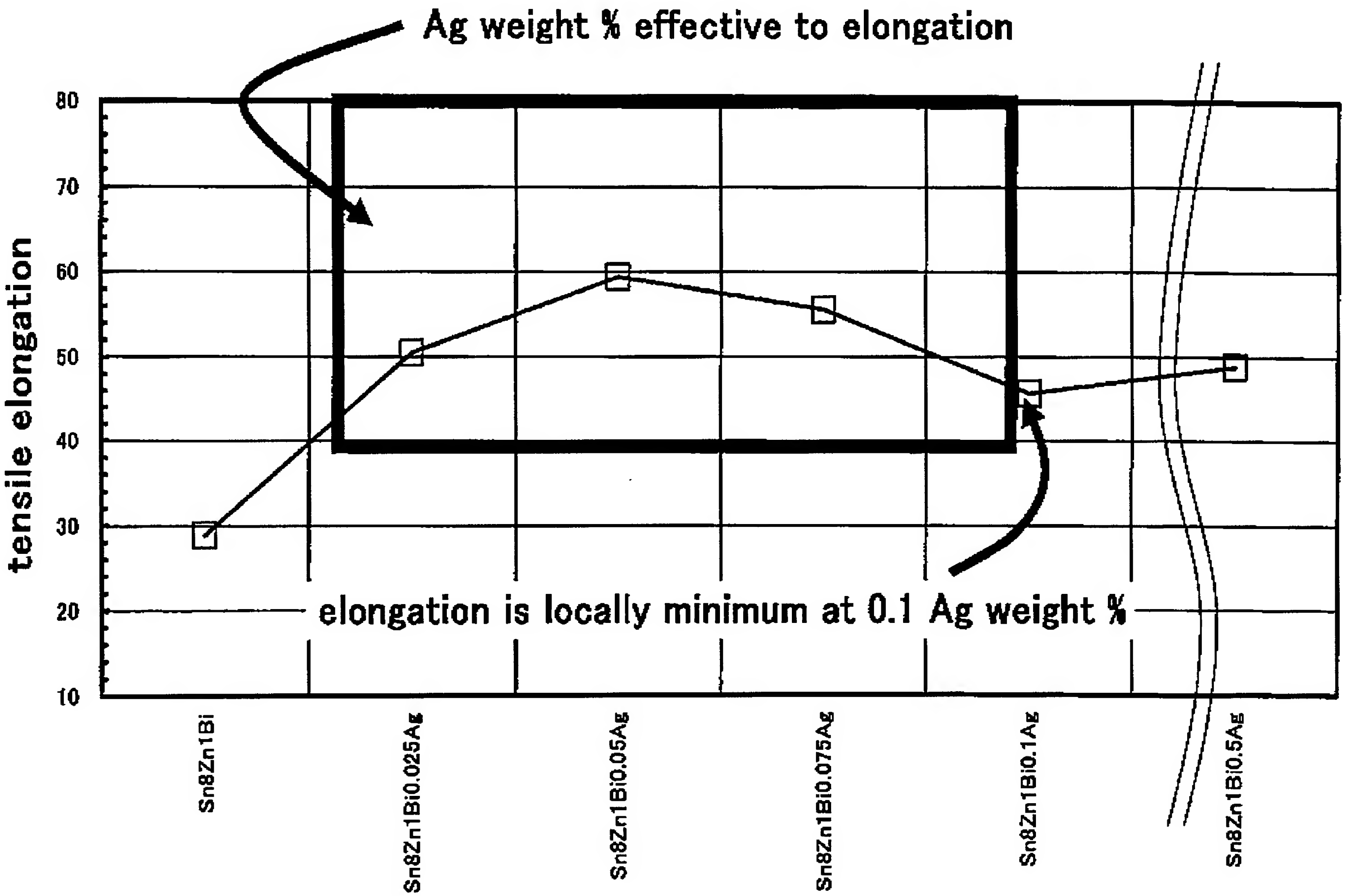

Ag weight % effective to elongation
tensile elongation
80
70
60
50
40
30
20
10
elongation is locally minimum at 0.1 Ag weight %
Sn8Zn1Bi
Sn8Zn1Bi0.025Ag
Sn8Zn1Bi0.05Ag
Sn8Zn1Bi0.075Ag
Sn8Zn1Bi0.1Ag
Sn8Zn1Bi0.5Ag

FIG.2

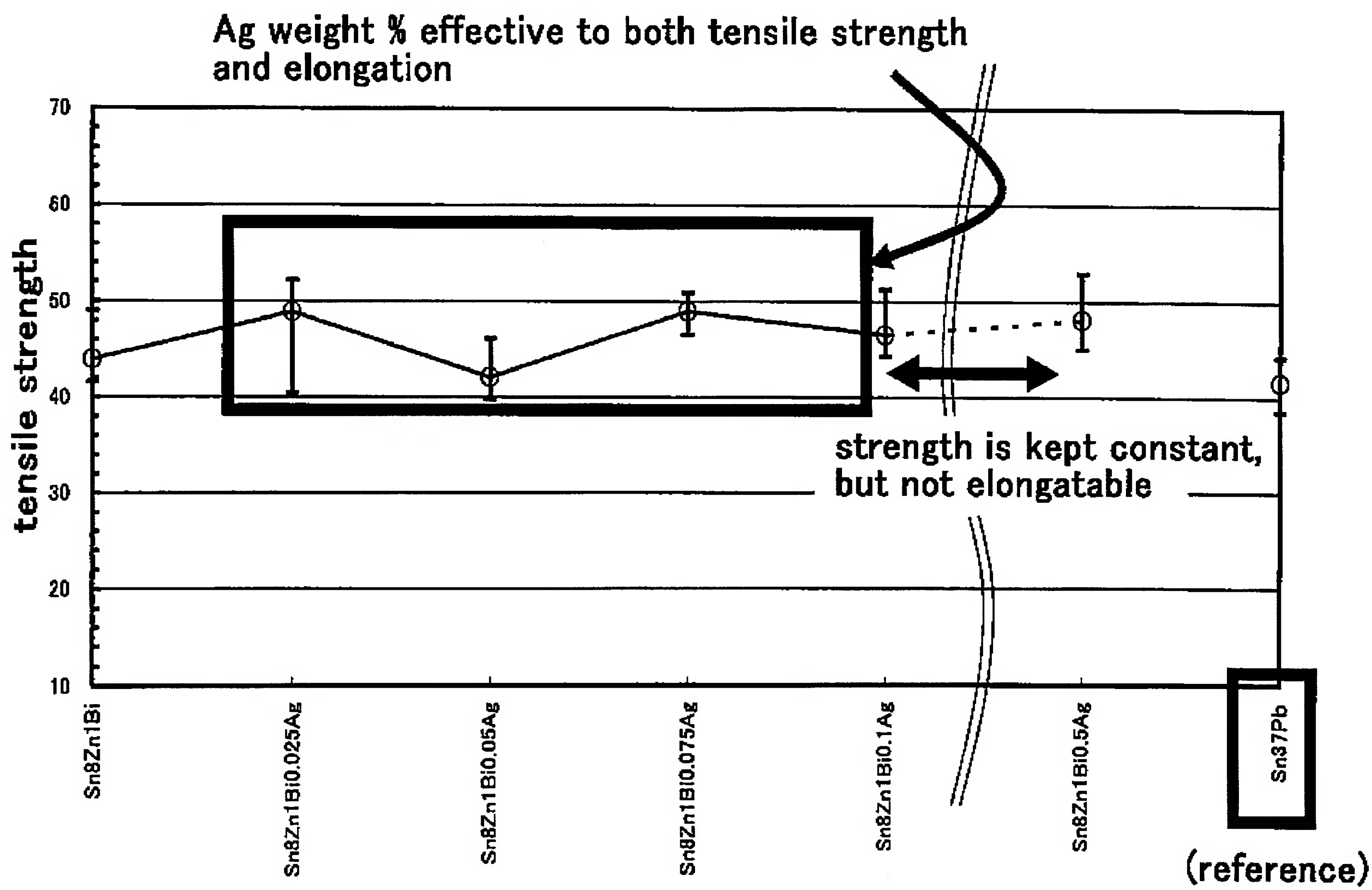
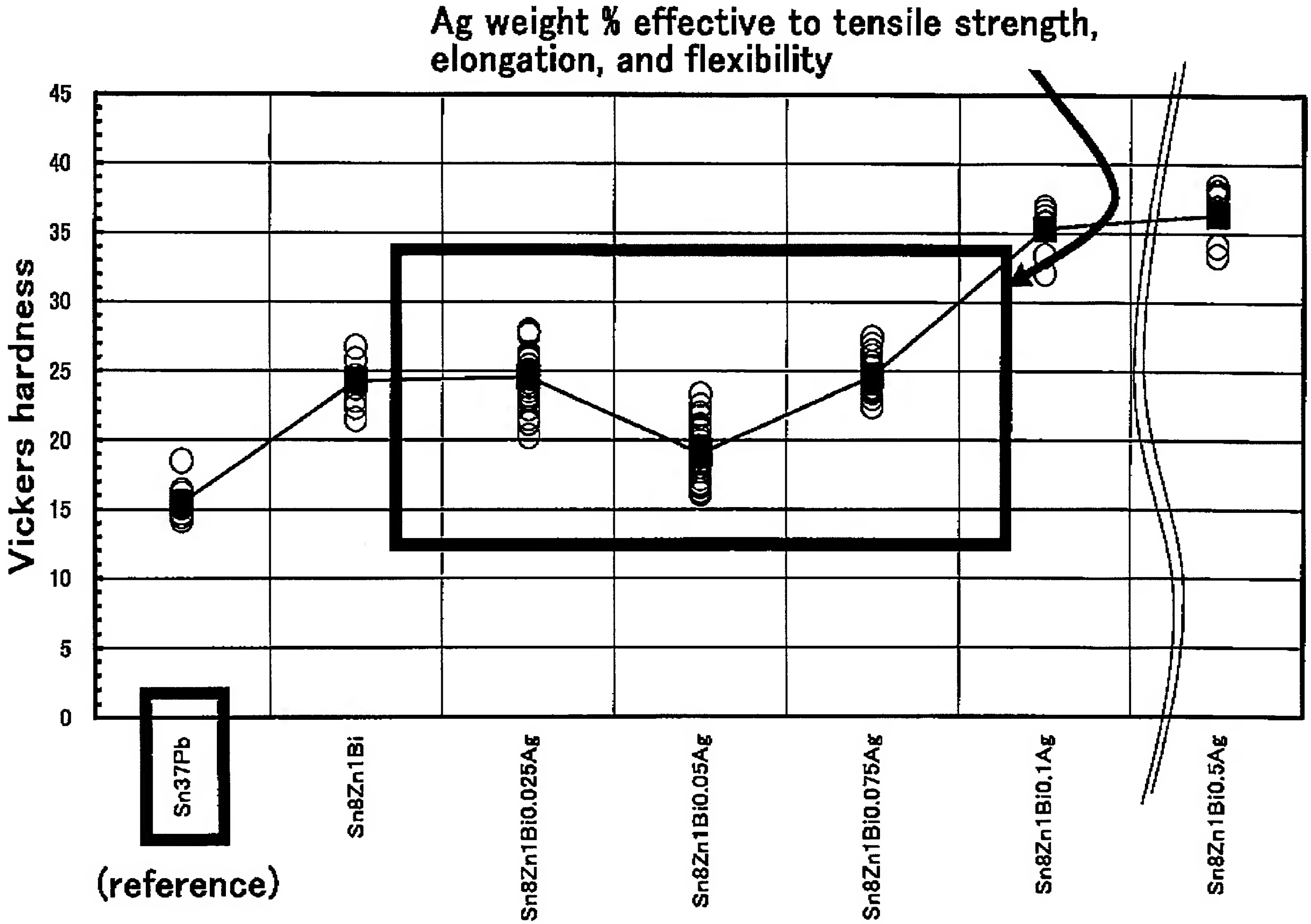
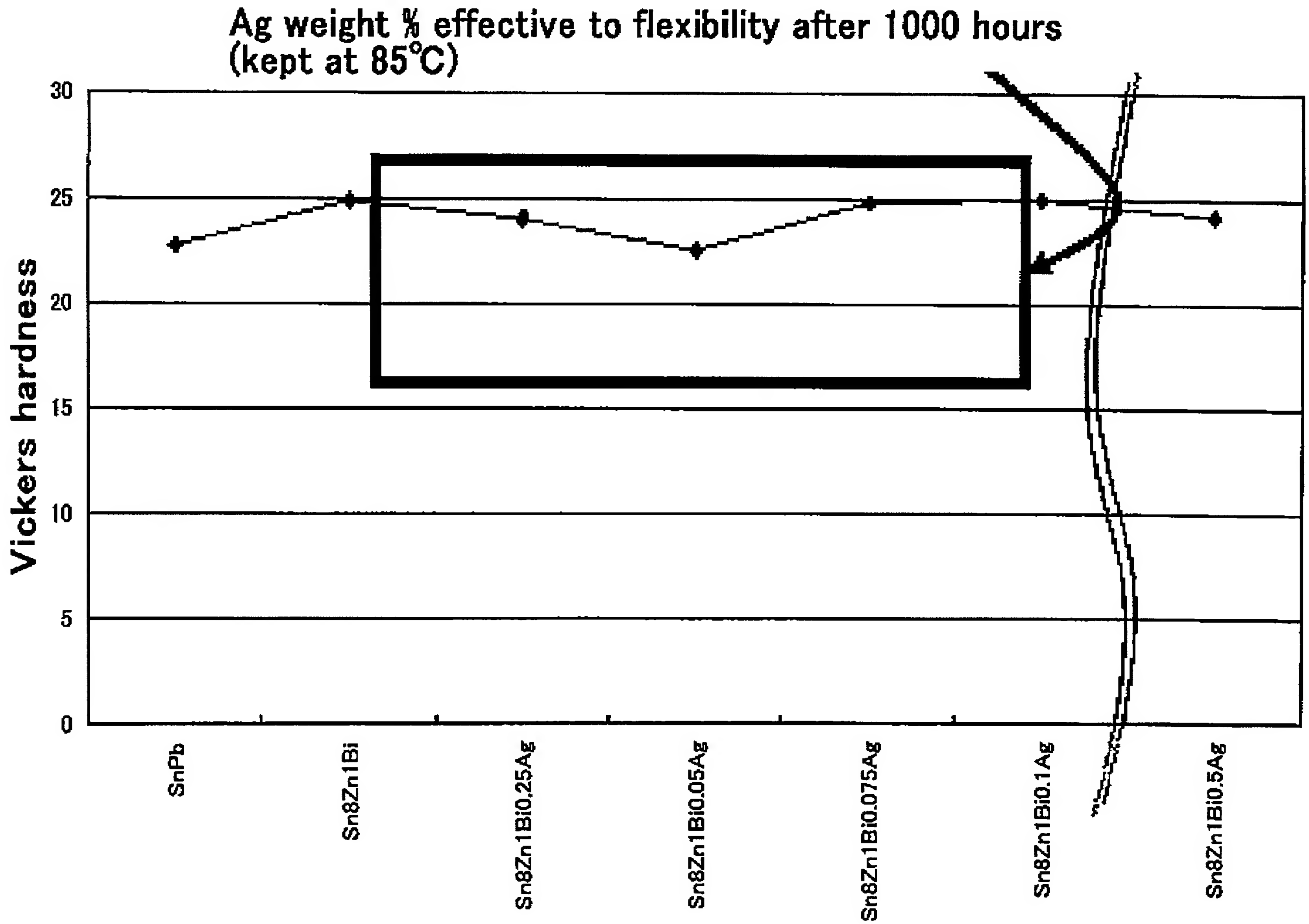

Ag weight % effective to both tensile strength and elongation
tensile strength
70
60
50
40
30
20
10
strength is kept constant, but not elongatable
Sn8Zn1Bi
Sn8Zn1Bi0.025Ag
Sn8Zn1Bi0.05Ag
Sn8Zn1Bi0.075Ag
Sn8Zn1Bi0.1Ag
Sn8Zn1Bi0.5Ag
Sn37Pb
(reference)

FIG.3



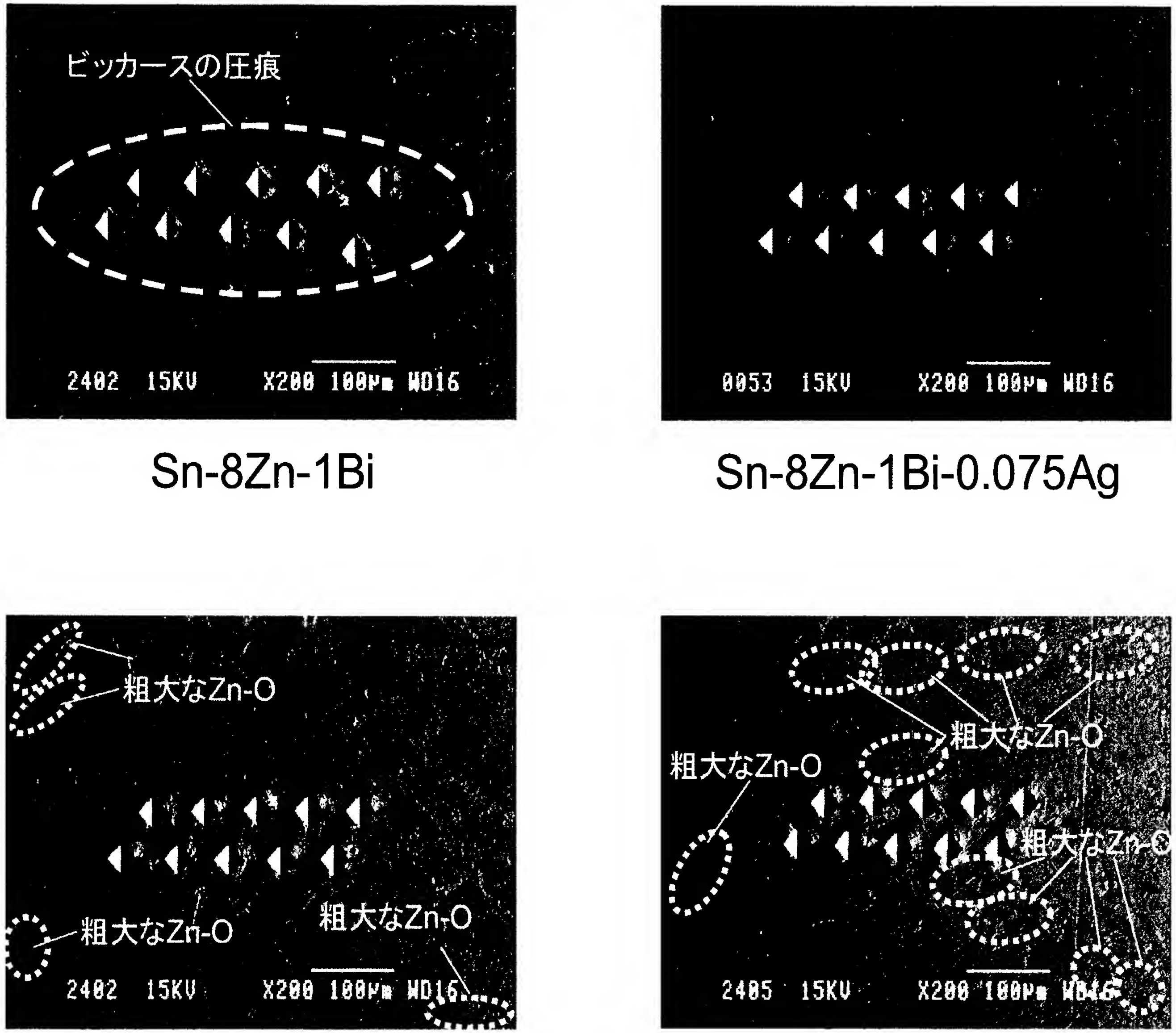
Ag weight % effective to tensile strength, elongation, and flexibility
Vickers hardness
0
5
10
15
20
25
30
35
40
45
Sn37Pb
(reference)
Sn8Zn1Bi
Sn8Zn1Bi0.025Ag
Sn8Zn1Bi0.05Ag
Sn8Zn1Bi0.075Ag
Sn8Zn1Bi0.1Ag
Sn8Zn1Bi0.5Ag

FIG.4



Ag weight % effective to flexibility after 1000 hours
(kept at 85°C)
Vickers hardness
30
25
20
15
10
5
0
SnPb
Sn8Zn1Bi
Sn8Zn1Bi0.25Ag
Sn8Zn1Bi0.05Ag
Sn8Zn1Bi0.075Ag
Sn8Zn1Bi0.1Ag
Sn8Zn1Bi0.5Ag

FIG. 5



Sn-8Zn-1Bi

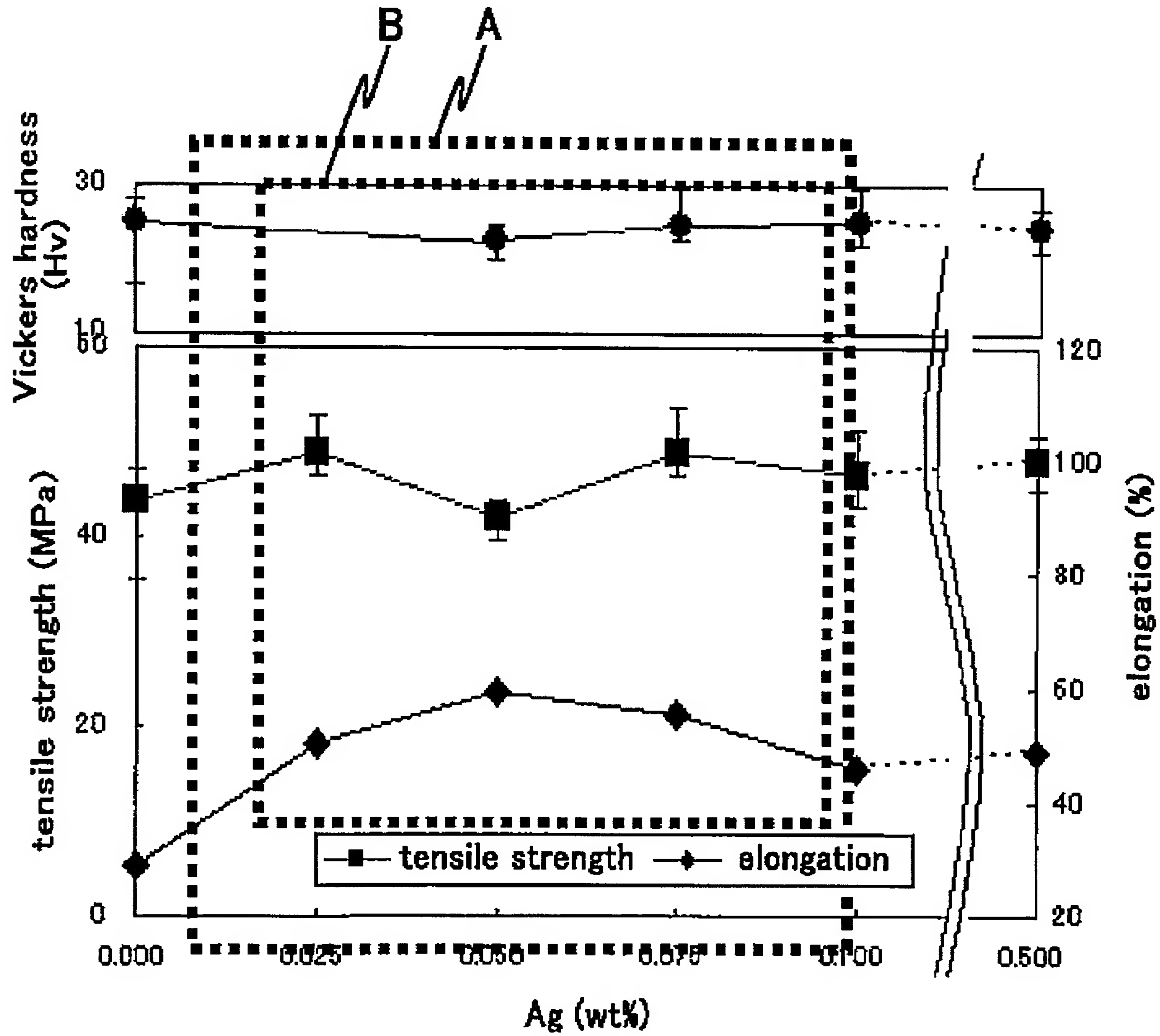
Sn-8Zn-1Bi-0.075Ag

Sn-8Zn-1Bi-0.1Ag

Sn-8Zn-1Bi-0.5Ag

図５　85℃、1000時間保持後の合金組織SEM像

FIG.6



B
A
Vickers hardness (Hv)
30
10
60
40
20
0
tensile strength (MPa)
120
100
80
60
40
20
elongation (%)
tensile strength
elongation
0.000
0.025
0.050
0.075
0.100
0.500
Ag (wt%)